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Mercuric Sulfide
Absorption

HEALTH CONSULTATION

PROPOSED MERCURY CLEAN-UP LEVEL FOR THE EAST FORK POPLAR CREEK FLOOD PLAIN SOIL

US DOE OAK RIDGE RESERVATION

OAK RIDGE, ANDERSON COUNTY, TENNESSEE

CERCLIS NO. TN1890090003

Prepared by

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STATEMENT OF ISSUES

In April 1993, the Agency for Toxic Substances and Disease Registry (ATSDR) wrote a health consultation on mercury contamination in the East Fork Poplar Creek flood plain. The finding of the consultation was that mercury contamination in soil did exist at levels that could pose a health risk to residents in the area (1).

In January 1994, the U. S. Department of Energy (DOE) released a report that provided more sampling data and also suggested a clean-up level of 50 mg/kg mercury in soil (2). This clean-up level was based on the U. S. Environmental Protection Agency (EPA) reference dose for mercury and conservative assumptions about the potential exposure pathway and exposure doses that might occur through that pathway (2).

In June 1994, DOE released an addendum to their original report. They presented additional sampling data which suggested that the predominant forms of mercury found in the area were mercuric sulfide and metallic mercury and cited new studies concerning the lower absorption rates of these forms of inorganic mercury. Based on this new information, DOE now recommends a higher clean-up level of 180 mg/kg (3).

Some members of the local community have questioned DOE's shift in clean-up levels, and, in particular, they have questioned DOE's assumptions concerning mercury speciation and absorption. Because of these concerns, these community members requested a consultation from ATSDR on whether the modified clean-up level will be protective of public health.

In order to evaluate whether the new clean-up level will be protective, we analyzed the proposed level using a worst case scenario that bypasses the areas of scientific debate about speciation and absorption.

Our finding is that the 180 mg/kg clean-up level will be protective of public health.

Until the East Fork Poplar Creek flood plain is remediated, we continue to recommend the following interim actions to reduce exposures: 1) post signs and restrict public access to areas with elevated mercury concentrations and 2) continue the East Fork Poplar Creek fish advisory.

BACKGROUND

1993 ATSDR Health Consultation

The 1993 ATSDR health consultation evaluated the existing health threat posed by chemical releases into the East Fork Poplar Creek flood plain by reviewing limited soil, sediment, surface water, air, and groundwater summary data from the East Fork Poplar Creek Remedial Investigation Report Phase IA and summary fish data from the DOE Biological Monitoring and Abatement Program. ATSDR concluded that mercury in soil and sediment in some areas along the East Fork Poplar Creek flood plain posed a threat to public health, especially to children playing in the flood plain (1). ATSDR recommended either advising the public that soil and sediment in the East Fork Poplar Creek flood plain was contaminated with mercury or restricting access to areas with elevated concentrations of mercury (1).

1994 DOE Remedial Investigations

In January 1994, DOE released the remedial investigation, which evaluated the extent and level of contamination in the 100-year East Fork Poplar Creek flood plain and established a preliminary clean-up level of 50 mg/kg (milligrams per kilogram) or ppm (parts per million) mercury in the flood plain soil to protect children who might eat the soil or come in contact with it. The preliminary level was based on the U.S. Environmental Protection Agency (EPA) guidance, EPA reference dose (RfD) for mercury, and site-specific exposure assumptions (2).

In June 1994, DOE released an addendum to the remedial investigation, which presented the results of additional studies of mercury in the East Fork Poplar Creek flood plain soil. In the addendum DOE stated that several different analytical methods indicated that mercuric sulfide and metallic mercury are likely to be the dominant inorganic mercury forms present and that mercuric chloride (the most easily absorbed and the most toxic inorganic form of mercury) is a minor component of the total mercury in the East Fork Poplar Creek flood plain soils (3). DOE also stated the weight of evidence supports their hypothesis that these predominant forms of mercury in the flood plain soil are less soluble, less bioavailable (not as easily absorbed into the bloodstream), and less toxic than the highly soluble mercuric chloride used to develop the preliminary clean-up level (3). Based on this evidence, DOE recommended a higher clean-up level of 180 mg/kg mercury in soil by reducing the bioavailability factor in their calculations from 100 to 30 percent (3).

Request for Health Consultation

Some local residents are concerned about the new recommended clean-up level. In particular, they have questioned DOE's assumptions concerning the speciation and bioavailability of mercury in the flood plain soil. These citizens have asked ATSDR to

evaluate whether the recommended clean-up value of 180 mg/kg mercury in the East Fork Poplar Creek flood plain soil will be protective of public health.

To evaluate whether the recommended mercury clean-up level is protective, we bypassed the areas of scientific debate about speciation and bioavailability of mercury in the flood plain soil and analyzed the 180 mg/kg mercury clean-up level using a worst case scenario.

WORST CASE SCENARIO

This scenario evaluated children who live close to East Fork Poplar Creek and play in the East Fork Poplar Creek flood plain soils. This worst case exposure scenario was selected because it uses the most sensitive population (children) exposed to the most highly absorbable form of inorganic mercury (mercuric chloride and metallic mercury) by the most probable exposure routes. The most probable route of exposure to inorganic mercury in soil would be swallowing dust and dirt, and the primary route of exposure to metallic mercury in soil would be breathing mercury vapors in the air (4).

Mercury in Soil

We estimated a child would receive 0.001 mg/kg/day of mercury (milligrams of mercury for every kilogram of the child's body weight everyday) if the child daily swallowed a small amount of dirt (e.g., from mouthing toys or fingers with dust on them) containing 180 mg/kg mercuric chloride[1]. We used mercuric chloride in our calculations because studies have shown it is highly soluble and more of it will be absorbed across the stomach and walls of the intestine than other forms of inorganic mercury. To determine if this "worst case" dose poses a health hazard, we then examined recent U. S. Public Health Service studies of animals fed mercuric chloride.

Animal studies have been used to define a no-observed-adverse-effect level (NOAEL) of 0.23 mg/kg/day for intermediate exposure (more than fourteen days but less than one year) to inorganic mercury and a lowest-observed-adverse effect level (LOAEL) of 1.9 mg/kg/day for chronic exposure (more than one year) to inorganic mercury (4, 5). The NOAEL is the amount of mercury animals ingested five days a week for six months without any adverse health effect (4, 5). The LOAEL is the smallest amount of mercury animals ingested five days a week for two years that produced an adverse health effect (4, 5). For inorganic mercury, the adverse effects first observed in the animals were minor changes in the kidneys and weight loss. More serious kidney effects were seen at a higher dose of mercury. Our

different from value of 0.317 mg/kg/day used in development of RfD (Bernaudsen et al, 1981)

[1] The estimated oral exposure dose for the worst case scenario assumes a mercury concentration of 180 mg/kg in soil, a soil ingestion rate of 100 mg soil per day, an exposure factor of 1 for exposure everyday, and a body weight of 16 kg for children 1 through 6 years old.

USEPA applied UF of 1,000 to LOAEL to ~~determine~~ derive RfD

calculated chronic oral exposure dose of 0.001 mg/kg/day for children is approximately 1,900 times *less than* the chronic LOAEL of 1.9 mg/kg/day and 230 times *less than* the intermediate NOAEL of 0.23 mg/kg/day. Thus, our estimated chronic oral exposure dose for the worst case scenario is much lower than the LOAEL and NOAEL.

Mercury in Air

In our evaluation of the danger of inhaling mercury vapor from the flood plain soil, we considered the air concentrations of mercury vapor that were measured over flood plain areas with the maximum mercury concentrations in soil. Long-term air monitoring indicates the concentration of mercury vapor ranged from 0.0000031 to 0.0000124 mg/m^3 (milligrams of mercury per cubic meter of air) in air over soil containing up to 3,000 mg/kg mercury (milligrams of mercury per kilogram soil) (2). To determine the health hazard of inhaling mercury vapor, we examined studies of people occupationally exposed to metallic mercury vapor (the most toxic form for inhalation). A chronic occupational human study was used to define the lowest-observed-adverse-effect level (LOAEL) of 0.026 mg/m^3 for chronic exposure to mercury vapor in air (4, 6). In that study the adverse effect observed was an increase in the fine tremors that all people have normally. There is also some indication from other studies that some memory loss and mild kidney effects may occur at this LOAEL. The maximum concentration of mercury vapor measured in air over the flood plain (0.0000124 mg/m^3) is 2000 times *less than* the LOAEL of 0.026 mg/m^3 (2, 4, 6). Thus, air concentrations of mercury vapor over flood plain soil at its present level of contamination are much lower than the LOAEL. The air concentrations of mercury vapor over soil with only 180 mg/kg mercury will be even lower.

DISCUSSION

Exposure Routes

We have considered a worst-case scenario involving children who are exposed to mercury in East Fork Poplar Creek flood plain soil at a clean up level of 180 mg/kg of mercury. Our assumptions provide a substantial margin of safety in assessing the health hazard to the community.

The residential land use scenario provides the maximum opportunity for chronic exposure to the mercury in the East Fork Poplar Creek flood plain soil. Children in the residential areas have the greatest risk of exposure to mercury because they are likely to have the most frequent and longest duration exposure to East Fork Poplar Creek soils since they play in the dirt and engage in frequent hand to mouth activity and often mouth objects.

The frequency and duration of exposure to East Fork Poplar Creek flood plain soil is likely to be much less for adults in general and particularly for people who do not live on the flood

plain. Within the commercial, DOE, and recreational (e.g., sportsman club and golf course) areas, access to the flood plain is either difficult or restricted. Within the agricultural areas, people intermittently enter the flood plain. Consequently, people would more probably have infrequent and short-duration exposures to mercury via ingestion of inorganic mercury in soil or inhalation of mercury vapors in the air.

Ingestion of Mercury From Soil

We believe the proposed clean-up level of 180 mg/kg of mercury in East Fork Poplar Creek flood plain soil will pose no health threat to children or adults.

Swallowing dirt is the most probable route of exposure to inorganic mercury compounds in the East Fork Poplar Creek flood plain. The hazard from ingesting inorganic mercury is primarily based on absorption into the bloodstream (internal dose). Different forms of inorganic mercury compounds (mercuric chloride and mercuric sulfide are different "forms" of mercury) have different absorption rates. Most of our information on absorption of inorganic mercury after ingestion is from animal studies that used mercuric chloride.

We do not have any direct measures of the amount of mercury that children would absorb (7, 8). No laboratory studies are available on the percent absorption of inorganic mercury from the gastrointestinal tract in humans (4). However, we know mercury can be absorbed by this route because mercury has been detected in humans who have ingested inorganic mercury compounds (mercuric nitrate, mercuric chloride, mercuric sulfide) (14, 15, 16).

Detailed animal studies indicate absorption of inorganic mercury across the gut is limited and is influenced by the form of mercury and by an animal's age and diet, as well as its species. For example, young rats may absorb much more mercury than old mice. Mercuric chloride, the compound we used for our estimate, is used in many animal studies because it is very soluble in water and is believed to have the highest absorption rate of inorganic mercury. The absorption for mercuric chloride by this route ranges from as little as 1% to as much as 38% in mice and rats (8, 9, 10). Studies suggest that some forms of mercury, for example mercuric sulfide, have lower absorption rates or "bioavailability" through the gut than mercuric chloride (11, 12, 13, 14). However, the relative bioavailability of mercuric sulfide versus mercuric chloride has not been specifically studied in animals nor has it been examined in humans (4). On the other hand we are reasonably certain that absorption is much lower (approximately 0.1%) for liquid metallic mercury (4). For this reason, ingestion of metallic mercury is much less hazardous than ingestion of mercuric chloride. In contrast, metallic mercury is dangerous if its vapor is inhaled, because metallic mercury vapor is easily absorbed through the lungs (4).

Both animal and human data indicate that, after absorption into the blood, inorganic mercury compounds go throughout the body but primarily accumulate in the kidneys (4). In animals, the kidneys had the highest mercury levels following acute and intermediate oral exposure to

mercuric chloride (11). For mercuric sulfide, higher doses were necessary before accumulation was noted in the kidneys (11, 13, 14). The accumulation of mercury in the brain and fetuses following ingestion of inorganic mercury compounds is substantially lower than in the kidneys because the lipid solubility of inorganic mercury compounds is poor, which prevents inorganic mercury compounds from crossing the blood-brain and placental barriers (17). Taken together, these studies have shown that renal toxicity is the most sensitive end point after ingestion of inorganic mercury.

Basis for Ingestion NOAEL and LOAEL: The no-observed-adverse-effect level (NOAEL) is a dose of mercury that is based on the highest dose of mercury for which no adverse health effect has ever been observed in animals. Specifically, the highest NOAEL of 0.23 mg/kg/day for intermediate oral exposure to inorganic mercury is based on rats given mercuric chloride in an aqueous solution by gavage for five days a week for six months (4, 5). Our calculated worst case oral exposure dose of 0.001 mg/kg/day for children is approximately 230 times *less than* this NOAEL.

The lowest-observed-adverse effect level (LOAEL) is also protective because it's based on the lowest dose where any adverse effect has been observed in the kidneys of animals. The intermediate LOAEL of 0.46 mg/kg/day (derived from six-month mercuric chloride study) is based on a sensitive biomarker for the first appearance of renal toxicity, increased kidney weight (4, 5). The chronic LOAEL of 1.9 mg/kg/day for inorganic mercury is based on microscopic changes to certain components of the kidney (thickening of glomerular and tubular membranes), changes that are likely to indicate more serious effects than kidney weight change alone (4, 5). This chronic dose is derived from a two-year study in rats that were exposed five days a week for two years to mercuric chloride in an aqueous solution by gavage (4, 5). Only male rats experienced an adverse effect in their kidneys at this dose, female rats did not. Furthermore, although adverse effects were seen in female mice in the same study at a higher dose (3.7 mg/kg/day), the effects appeared less severe than in males. Taken together, this and other evidence suggests that male rats may be particularly sensitive to the effects of mercury exposure. The calculated chronic oral exposure dose of 0.001 mg/kg/day for children is approximately 460 times *less than* the intermediate LOAEL of 0.46 mg/kg/day and 1,900 times *less than* the chronic LOAEL of 1.9 mg/kg/day.

It is important to be cautious when generalizing from animal data. NOAELs and LOAELs based on animal data are not human health guidelines per se. There is uncertainty in extrapolating from them for the following reasons:

1) Rat data may not be directly applicable to humans (e.g., humans may be more sensitive than rats).

2) Individuals may have different responses (some humans are likely to be more sensitive than the average).

3) Using a LOAEL does not give a clear threshold below which adverse effects do not occur (i.e., we are not sure how much lower than the LOAEL we would have to go before we would stop seeing the adverse effect entirely) .

However, we are confident that the proposed clean-up level of 180 mg/kg of mercury in the flood plain soil will pose no health threat because the estimated oral exposure dose is so much lower (2 to 3 orders of magnitude) than the relevant NOAEL and LOAELs.

We also don't expect adverse effects on other organ systems because the amount of mercury necessary to cause adverse effects is higher for other organs than it is for the kidneys. For example, no evidence of neurotoxicity was seen in mice administrated 0.74 to 2.2 mg/kg/day of mercuric chloride in drinking water for 110 days and 7.4 to 14.8 mg/kg/day for an additional 400 days (18). Also, no histopathological evidence of brain lesions was observed in rats receiving doses of mercuric chloride as high as 3.7 mg/kg/day by gavage, five days a week, for up to two years, or in mice receiving doses as high as 7.4 mg/kg/day by gavage, five days a week, for up to two years (4, 5).

Finally our worst case ingestion scenario evaluates all the mercury in the East Fork Poplar Creek flood plain soil as mercuric chloride, which assumes that the bioavailability (absorption) of mercury in East Fork Poplar Creek soil is equivalent to that of mercuric chloride in an aqueous solution. This assumption is conservative because the majority of mercury forms in the soil are likely to be less bioavailable than mercuric chloride in aqueous solution. This assumption provides an additional margin of safety in assuring that exposure to East Fork Poplar Creek flood plain soil containing 180 mg/kg inorganic mercury will not result in adverse kidney effects.

Inhalation of Mercury In Air

We believe air concentrations of mercury vapor over the East Fork Poplar Creek flood plain soil will pose no health threat if soils are remediated to the proposed clean-up level of 180 mg/kg of mercury.

We predict very little exposure to mercury would take place through inhalation if soils are cleaned up to 180 mg/kg. However, inhalation is the most toxic route of exposure to metallic mercury. Therefore, we made conservative assumptions in the worst case scenario for this exposure route.

The primary route of exposure to metallic mercury in soil is inhalation of mercury vapors in the air. Once mercury vapors are inhaled, absorption into the bloodstream is substantial (4). Approximately 74-80% of inhaled elemental mercury vapor is retained in human tissue (19, 20). Following inhalation, mercury is distributed throughout the body and accumulates primarily in the kidney, as it does when ingested. However, the lipophilic nature of metallic

mercury also allows it to readily cross the blood-brain and placental barriers and accumulate in the brain and fetus (4, 17). Therefore, inhalation is a more toxic route of exposure.

Basis for Inhalation LOAEL: The central nervous system is the most sensitive target organ in humans following inhalation of metallic mercury vapor. The lowest-observed-adverse effect level (LOAEL) of 0.026 mg/m^3 for chronic inhalation exposure to mercury vapors in air is based on a study in which a significant increase in the average velocity of naturally occurring tremors was observed in workers exposed to mercury vapors (0.026 mg/m^3 average concentration) for an average of 15.3 years (range 1-41 years) (6). The range of mercury concentration (0.0000031 to 0.0000124 mg/m^3) measured in the air over flood plain soil containing 3,000 mg/kg mercury is over 2,000 times *less than* the LOAEL of 0.026 mg/m^3 (2, 4). Since air concentrations of mercury vapor over soil at 3,000 mg/kg mercury will be much higher than over soil at 180 mg/kg mercury, we think chronic exposure to mercury vapor from the East Fork Poplar Creek food plain soil with concentrations of 180 mg/kg mercury will not pose a health threat.

CONCLUSION

We conclude that the proposed soil clean-up level of 180 mg/kg mercury for the East Fork Poplar Creek flood plain is safe. Our estimated ingestion dose is orders of magnitude lower than the LOAEL and NOAEL for ingestion developed from U. S. Public Health Service studies of animals fed mercuric chloride. Also, the measured concentration of mercury vapors in the air are much lower than the LOAEL for chronic inhalation of mercury vapors. Consequently we think the 180 mg/kg clean-up level for the East Fork Poplar Creek flood plain soil will be protective for exposures through ingestion as well as through inhalation.

RECOMMENDATIONS

The following recommendations from ATSDR's previous health consultation should be implemented or remain in effect:

1. As an interim action, post signs and restrict public access to East Fork Poplar Creek flood plain areas with elevated mercury concentrations in the soil and sediment (1).

2. Continue the East Fork Poplar Creek fish advisory. Ensure that a sufficient number of signs are posted, especially at the confluence of Poplar Creek, to warn the public of the presence of contaminated fish in the creek (1).

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